Performance of Physical Structures in Hurricane Katrina and Hurricane Rita

Reconnaissance Findings and Recommendations

Visiting Committee on Advanced Technology
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Stephen A. Cauffman, Leader
Structures Group
Building and Fire Research Laboratory
National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce

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Overall Approach

- Multi-organizational reconnaissance of the performance and damage to physical structures.
  - 26 experts drawn from 16 private sector, academic, and government organizations.
- NIST-led reconnaissance was a cooperative effort from its very launch.
  - Data and information openly shared between NIST, other federal agencies, and private sector participants.
  - While findings and recommendations are those of NIST, the report and its recommendations have been reviewed by the participating organizations.
  - Interagency cooperation is continuing as agencies plan and carry-out follow up actions in response to recommendations.
- Complements other completed and ongoing studies of the performance of structures in the Gulf region.
- Only study to take a broad look at damage to physical structures (major buildings, infrastructure, and residential structures) and its implications for the Gulf Coast and other hurricane-prone regions.

Organizations Participating in NIST Team

- Federal agencies
  - National Institute of Standards and Technology
  - Federal Highway Administration
  - U.S. Army Corps of Engineers
- Private Sector Organizations
  - Applied Technology Council
  - Amtech Roofing Consultants, Inc.
  - Applied Residential Engineering Services
  - ImageCat, Inc.
  - International Code Council, Inc.
  - Scawthorn Porter Associates, LLC
  - Shiner Moseley and Associates, Inc.
  - Smith & Huston, Inc.
- Academic and Research Institutions
  - National Research Council, Canada
  - Texas Tech University
  - University at Buffalo, Multidisciplinary Center for Earthquake Engineering Research
  - University of Puerto Rico

Coordination with Other Agencies

- FEMA Mitigation Assessment Team
- U.S. Army Corps of Engineers
- Federal Highway Administration
- National Science Foundation
- National Oceanic and Atmospheric Administration
- Department of Housing and Urban Development
- U.S. Geological Survey

Key Findings on Codes, Standards, and Practices

- ***Critical importance of state and local entities adopting and then rigorously enforcing building standards, model codes, and practices.***
  - No statewide building code in Louisiana, Mississippi, Alabama, or Texas* at the time the hurricanes struck.
  - The City of New Orleans adopted the 2000 International Building and Residential Codes in January 2004.
  - Louisiana has adopted the International Codes (IBC, IRC, IEBC, and IMC) for the 11 parishes hardest hit by Katrina for rebuilding. The codes go into effect statewide in 2007.
  - The 2003 IBC was adopted statewide in Texas in September 2005 and went into effect statewide in Texas in January 2006.
  - Mississippi does not currently have a statewide building code. Local jurisdictions are permitted to set minimum standards for building construction.
  - Alabama does not currently have a statewide building code. Local jurisdictions are permitted to set minimum standards for building construction.
- The team identified opportunities for improvements in codes, standards, and practices that require no additional study.

Key Needs for Detailed Technical Studies

- Evaluate the performance of the New Orleans flood protection system and provide credible scientific and engineering information for guiding the immediate repair and future upgrade of the system.
- Develop risk-based storm surge maps for use in flood-resistant design of structures.
- Evaluate and, if necessary, modify the Saffir-Simpson hurricane scale's treatment of storm surge effects due to hurricanes.

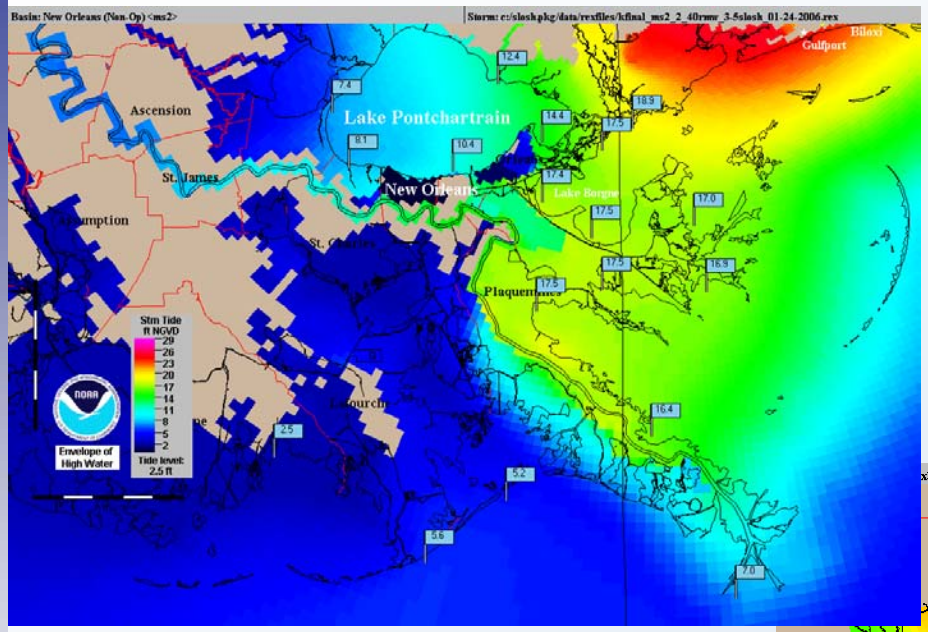
Principal Findings: Storm Surge

- In coastal areas and in New Orleans, storm surge was the dominant cause of damage.
- Storm surge heights and flooding, in general, exceeded the levels defined by existing flood maps and historical records.
- While design provisions exist to address storm surge and flooding, existing flood hazard maps – which provide the basis for design of structures – are outdated and not consistent with the risks posed by storm surge in these coastal areas.
- Better definition of the hazard from storm surge and coastal flooding is required to appropriately apply existing design provisions and elevation levels for buildings and residences.

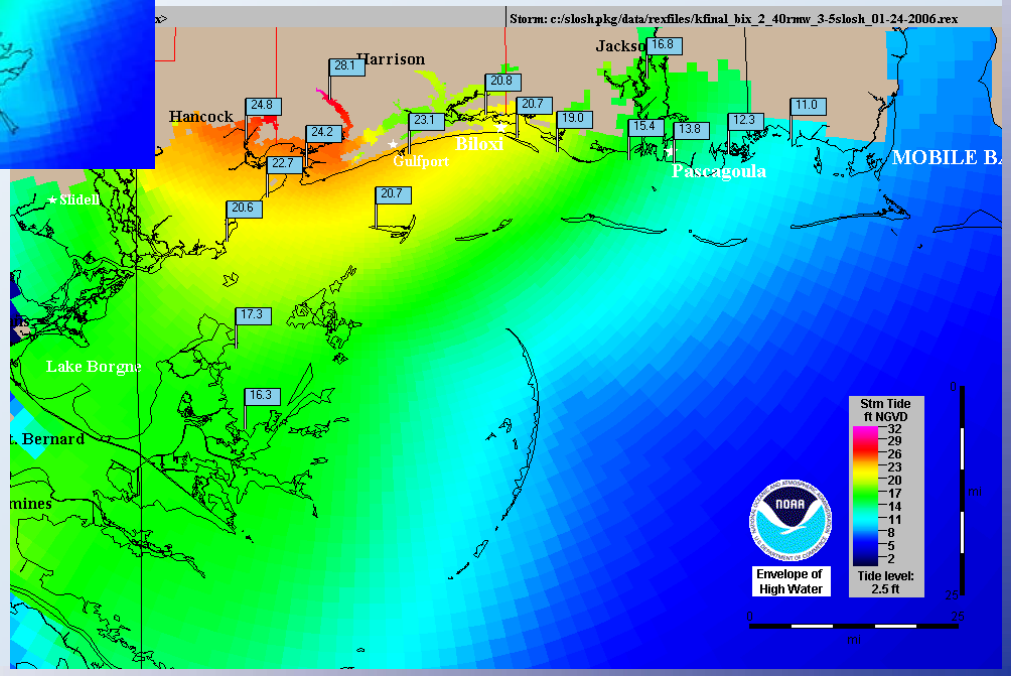
Principal Findings: Saffir-Simpson Scale

- The Saffir-Simpson Hurricane Intensity Scale specifies hurricane wind speeds and indicates storm surge heights associated with each category.
- Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region.
- Hurricane Katrina and Hurricane Rita demonstrated that it is possible for storm surge heights to substantially exceed heights associated with a specific hurricane intensity by the Saffir-Simpson scale.
- NOAA does not rely on the storm surge ranges associated with the Saffir-Simpson hurricane scale. Instead NOAA includes in its advisories storm surge forecasts based upon use of storm surge simulation models.

Storm Surge Hindcasts

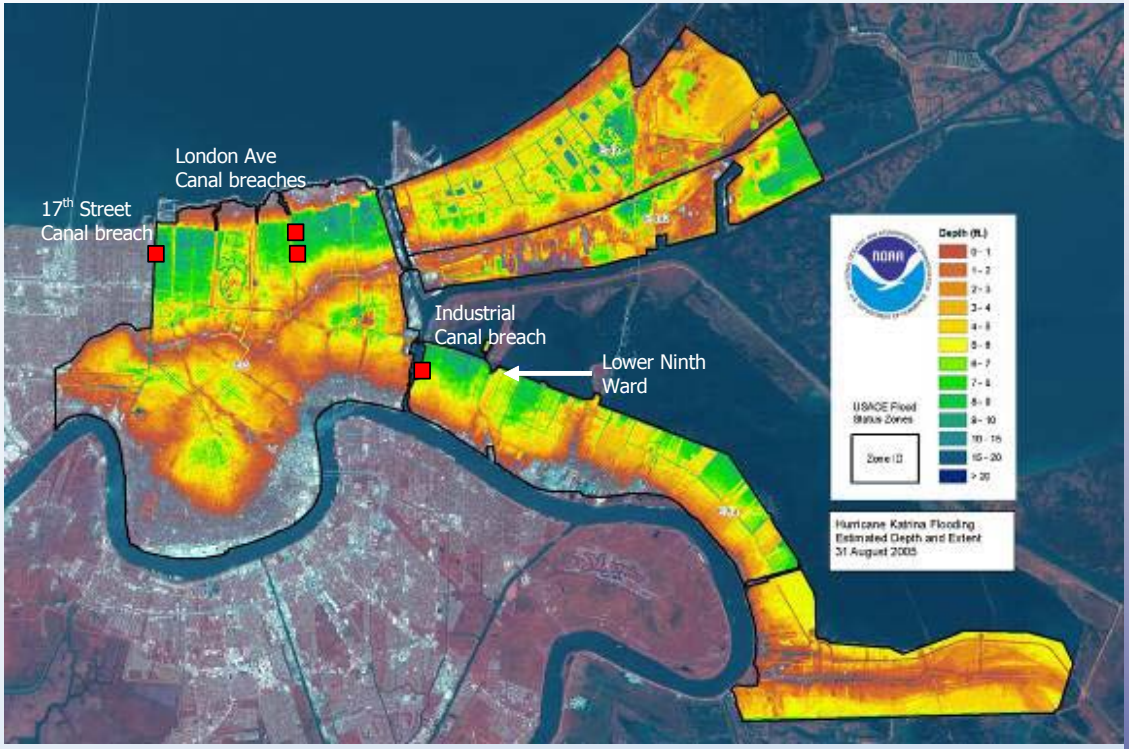


- Hindcasts of storm surge due to Hurricane Katrina for Gulf Coast and New Orleans.



New Orleans Flooding

- Major levee breaches in 3 canals
- 80 sq mi, 250,000 acre-feet of water
- 100,000 homes, much of downtown flooded
- Geotechnical movement implicated
- Peak flood depth ~2 ft higher than shown on 2 Sep map
- Many major buildings have basements w/critical equipment, etc.
- Humidity, standing water, and no air conditioning aggravated mold damage



Storm Surge Damage to Buildings

Damaged school recreational facility, Cameron, LA

Hibernia Bank building, Cameron, LA

Damaged strip mall, Creole, LA

Photo credits: Christopher Letchford, Texas Tech University

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Principal Findings: New Orleans Flood Protection System

- Storm surge and associated wave action led to breaches in the flood protection in New Orleans. This resulted in:
  - Significant damage to and destruction of adjacent residential structures due to high velocity water flow.
  - Flooding in approximately 75 percent of the city.
- The NIST-led team observed failures of the levees and floodwalls due to four different mechanisms:
  - Rotational failure of the floodwall-sheetpile system triggered by soil erosion (due to overtopping).
  - Massive erosion and scour of the earthen levee at the levee/floodwall junction (with overtopping).
  - Sliding instability of the floodwall-levee system due to foundation failure (without overtopping).

Rotational Failure of Floodwall-Sheetpile due to Scour (Overtopping)

Inner Harbor Navigation Canal (Lower Ninth Ward)

- **Rotational failure of floodwall-sheetpile due to overtopping and scour on protected side of levee.**

Photo credits: NIST

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Principal Findings: Bridges and Parking Structures

- Many bridges in coastal areas were damaged due to uplift and lateral loads imparted by storm surge and associated wave action.
- A number of simple span bridges lost spans or had spans displaced as a result of these actions.
- Some bridges, both highway and railway, exposed to these actions remained in place due to design features that prevented displacement of decks.
- Swing span bridges exposed to storm surged were in many cases rendered inoperable due to inundation of mechanical and electrical equipment.
- Failures of precast concrete parking garage structures were similar to those of simple span bridges, where uplift and wave forces dislodged first floor decks from their connections to columns.

Damage to Bridges Due to Storm Surge

- Deck sections lifted and displaced by storm surge and wave action.
- Decks were simply connected to bridge piers (no shear key present).

Photo credit: J. O'Connor, MCEER

Example of Good Performance of a Bridge Exposed to Storm Surge

- **Bridge subjected to storm surge.**
- **Deck sections were not lifted above the height of shear key and remained in place.**

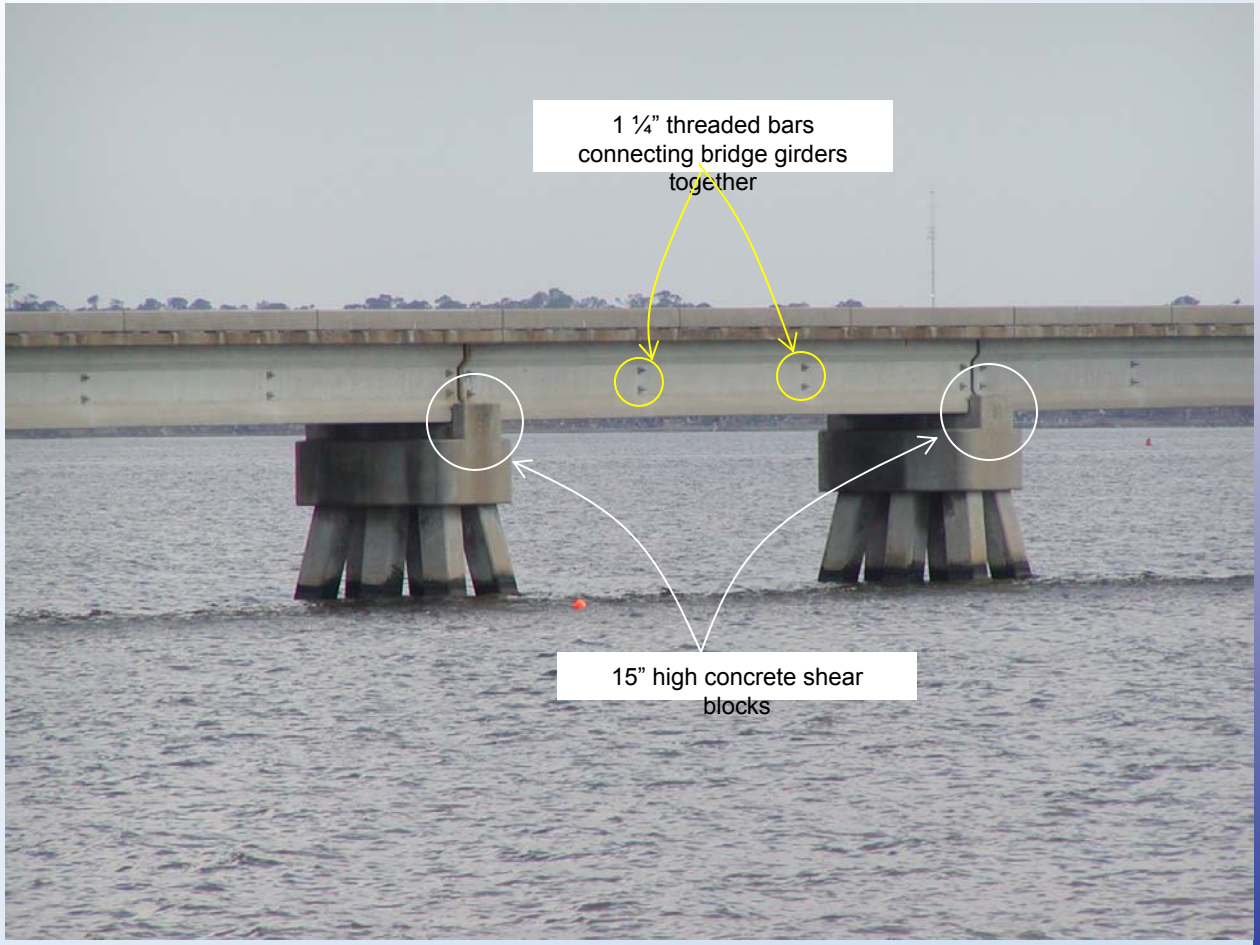
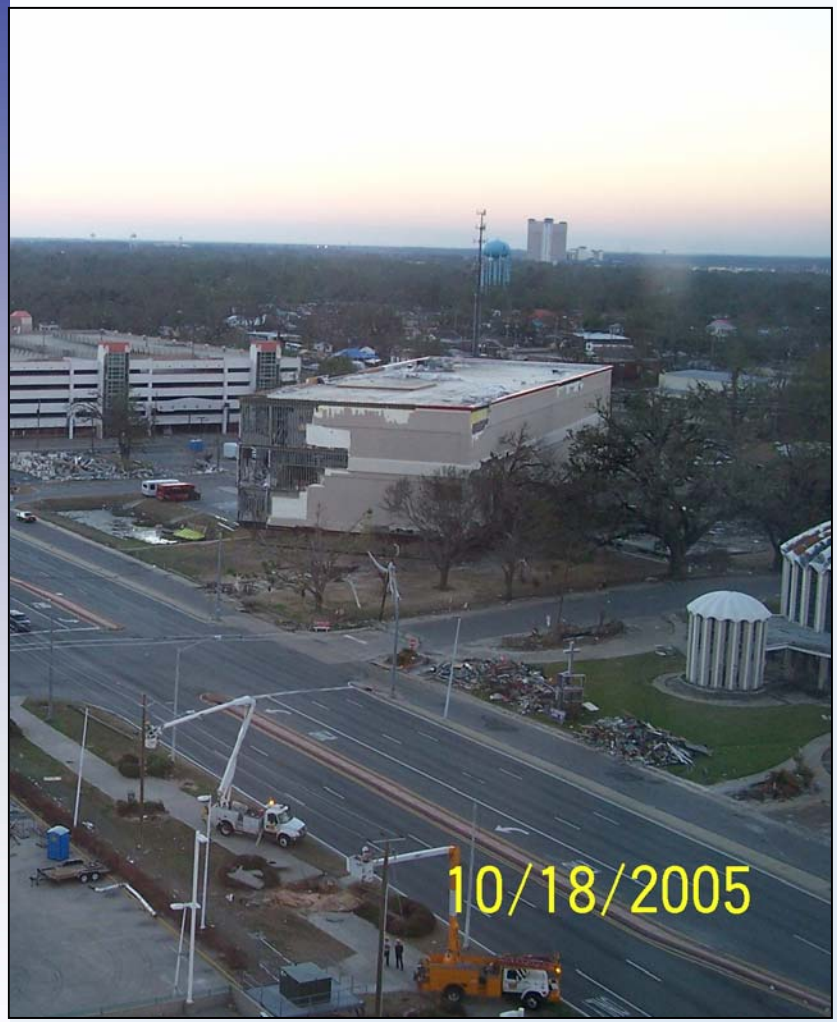


Photo credit: LA DOTD

Principal Findings: Moored Casino Barges

- In coastal Mississippi, storm surge, wave action, and surge-borne debris caused extensive damage to casino barges that either sank in place or broke free of moorings and floated inland.
- Mooring requirements, based on wind speeds of 155 mph and 15 ft storm surge were inadequate for the storm surge heights generated by Hurricane Katrina.
- There are no national standards for the design of mooring systems used to secure permanently moored facilities such as casino barges.

Failure of Casino Barge Moorings Due to Storm Surge



- Casino barge that broke free of moorings and floated inland.

- Casino barge impacted parking garage causing partial collapse of parking structure.
- Casino barge sank in place.

Photo credits: NIST

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Principal Findings: Operation of Critical Equipment

- Several buildings were rendered inoperable because critical equipment, such as backup generators, electrical equipment, and chiller plants, were located at or below grade and damaged due to inundation by floodwaters.

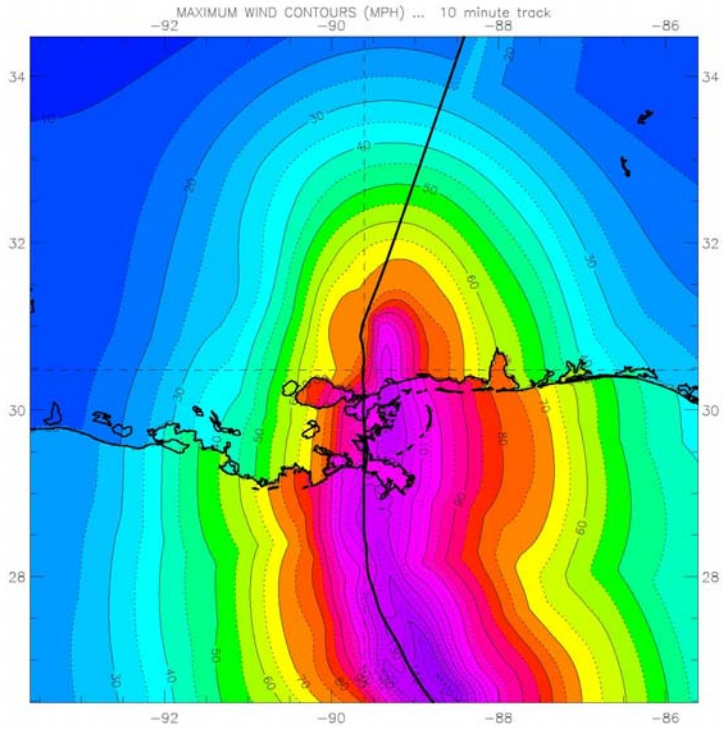
- Current model codes and standards contain provisions for the design of structures and location of equipment to account for flooding and storm surge.

Principal Findings: Wind and Wind-Induced Damage to Structures

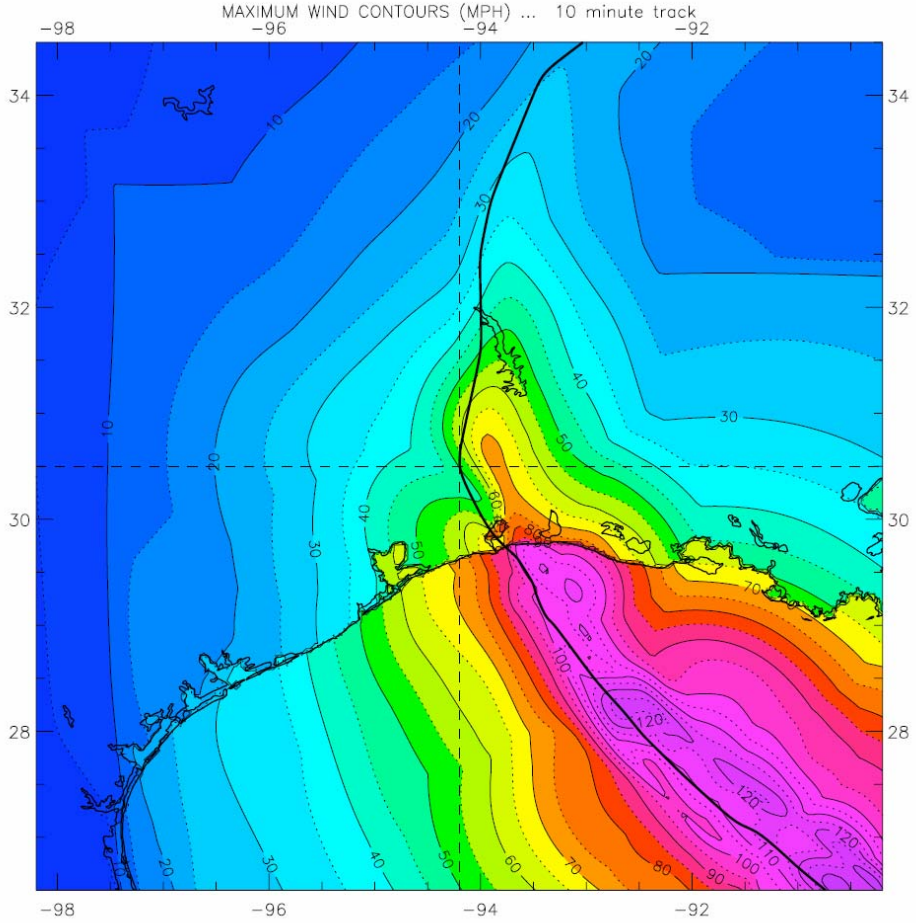
- Away from the immediate coastal areas, wind and wind-borne debris were the dominant causes of damage to structures.
- In general, wind speeds were below levels required by codes and standards.
- Wind caused damage to roofing and rooftop equipment, providing paths for water ingress into buildings.
- Wind-driven rain through walls and around intact windows also was responsible for water damage to the interiors of buildings.

Environmental Conditions – Wind Speed Data

Katrina



Rita



- **Wind speeds in affected areas were at or below design wind speeds.**
- **Wind speeds diminish rapidly as hurricane passes over land.**

3-s gust speeds are 20 to 25 percent greater than the 1 min averages shown

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Principal Findings: Wind and Wind-Borne Debris Damage to Major Buildings

- Major buildings suffered wind-induced damage to glazing (windows) as a result of debris from:
  - Aggregate surface roofs on adjacent buildings
  - Damaged equipment screens on top of buildings
  - Damaged façade or structure of adjacent buildings
- In many cases, buildings that suffered structural damage were built before current model building codes were available.
- Design wind speeds in current codes and standards provide a sufficient level of safety if provisions are properly implemented and enforced.

Wind-Borne Debris Damage to Windows

Photo credit: Keith Porter, Scawthorn Porter Associates

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Recommendations

- As a part of its reconnaissance, NIST is making 23 recommendations for specific improvements in the way buildings, physical infrastructure, and residential structures are designed, constructed, maintained, and operated in hurricane-prone regions.
- These recommendations are grouped as follows:
  - Immediate impact on practice for rebuilding (5)
  - Standards, codes, and practices (9)
  - Further study and research and development (9)
- The recommendations call for action by specific entities regarding standards, codes, and regulations as well as their adoption and enforcement; professional practice, education, and training; and research and development.

Recommendations (2)

- ***NIST believes that the recommendations are realistic, appropriate, and achievable within a reasonable period of time.***

- Most of the recommendations deal with adopting and enforcing current requirements or with making improvements to existing requirements and practice. Some of the recommendations address developing a risk-consistent basis for consideration of storm surge as a design load for coastal buildings and structures.

- **NIST does not prescribe specific systems, materials, or technologies.** Instead, NIST encourages competition among alternatives that meet performance requirements.

- **The recommendations do not prescribe threshold levels.** NIST believes that this responsibility properly falls within the purview of the public policy setting process, in which the standards and codes development process plays a key role.

Adoption and Enforcement of Codes and Standards

- ***NIST strongly urges state and local agencies to adopt and enforce building codes and standards since such enforcement is critical to ensure the expected level of safety.*** In many cases, the reconnaissance clearly found that building codes, standards, and practice are adequate to mitigate the types of damage that resulted from the hurricanes.

- ***Following good building practices is critical to better performance of structures during extreme events such as hurricanes.*** Relatively straightforward changes to practice could have reduced the damaged that occurred.

Adoption and Enforcement of Codes and Standards (2)

- The best codes and standards cannot protect occupants unless they are strictly followed. Examples include:
  - Masonry wall failures observed during the reconnaissance may have been prevented had they been properly anchored and reinforced as required by model codes.
  - Many roofing shingle failures resulted from installers using an inadequate number of fasteners or installing fasteners in the wrong locations.
  - Wind-borne gravel from building rooftops caused a great deal of damage to windows on nearby structures.
  - In many instances, backup electrical generators, electrical equipment, chillers and other equipment were not placed above the expected flood levels.

Actions Already Underway

- Federal agencies, state and local governments, and the private sector have already taken actions that are consistent with NIST's recommendations. NIST encourages other organizations with responsibility for implementation to take similar actions.
- Levees and Floodwalls
  - USACE immediately began a major project (Project Guardian) to rebuild the levees and floodwalls where breaches occurred before the start of the hurricane season on June 1, 2006.
  - USACE initiated the Interagency Performance Evaluation Task Force (IPET) to assess the performance of the New Orleans flood protection system, understand the factors that contributed to failures during Hurricane Katrina, and make recommendations for improvements.
- Building Code Adoption and Other Actions
  - Louisiana has adopted the International Building Code (IBC) in the 11 parishes hardest hit by Hurricane Katrina effective immediately for reconstruction. The IBC will become effective statewide in 2007.
  - The Mississippi Legislature (House Bill 45) amended the Mississippi Code of 1972 to allow the gaming portions of Gulf Coast casinos to be built on land.
  - The Department of Housing and Urban Development (HUD) requires that community development block disaster recovery grants not be used for any activity in special flood hazard areas.

Actions Already Underway (2)

- Flood Map Modernization and Storm Surge Mapping
  - FEMA, leading the effort, in cooperation with the USACE, has undertaken a project to update the Flood Insurance Rate Maps for New Orleans and the Gulf Coast areas affected by Hurricane Katrina and Hurricane Rita.
  - The Office of the Federal Coordinator for Gulf Coast Rebuilding, FEMA and USACE have issued guidelines for rebuilding in New Orleans and the surrounding areas.
  - The USGS have initiated a project to map the changes in the coastline due to the effects of storm surge. The agency also plans to study the effects of natural and restored land in mitigating the effects of storm surge.
  - NIST has funded a project to develop the methodology for risk-based structural design criteria for coastal structures subjected to both hurricane winds and storm surge.

Actions Already Underway (3)

- Highway Bridges
  - FHWA issued an initial guidance document on “Coastal Bridges and Design Storm Frequency.” This document provides a regulatory and engineering rationale for considering both storm surge and wave forces, specifically for those coastal states affected by Hurricane Katrina.
  - FHWA is developing a plan of action that will be used to coordinate with AASHTO and other stakeholders in performing studies and research for coastal bridges vulnerable to scour and hydrodynamic forces.
  - FHWA has issued a solicitation for a pooled funds project to develop retrofit strategies and options to mitigate damage to highway bridges subject to coastal storm hydrodynamic factors and recommend improvements for bridges in coastal environments.

Selected Recommendations

Improve the design, construction, and performance of the ***New Orleans levees and floodwalls*** by: (1) conducting a comprehensive review and upgrade of the design hazard, criteria, and manuals for levees and floodwalls to develop a risk-based approach for storm surge that is similar to risk-based design for wind; (2) performing a systematic review of the existing, as-constructed levees and floodwalls relative to design requirements in USACE design manuals; and (3) developing methodologies for levee and floodwall design, construction, and repair that allow for overtopping without subsequent failure of the floodwall or levee structures. *#1*

Install mechanical, electrical, and plumbing components, equipment, and systems—including alternative/backup electric power supplies—required for the ***continued operation of existing critical facilities*** at a level above the design flood elevation by a specified minimum threshold. *#2*

States and local jurisdictions should consider (1) ***licensing*** of roofing contractors; (2) ***continuing education*** of roofing contractors; and (3) ***field inspection programs*** to monitor roofs under construction for proper installation, in order to ensure acceptable roofing application. *#5*

Evaluate and upgrade ***mooring system design criteria for floating structures*** (e.g., casino barges) to be consistent with the wind and storm surge risk including dynamic wave loads. #6

Selected Recommendations (2)

Develop ***risk-based storm surge maps*** for several mean recurrence intervals, incorporating storm surge height and current velocity and the associated wave action, to provide a technical basis for the design of coastal structures in storm surge zones along the U.S. Atlantic and Gulf Coast regions. #7

Evaluate and, if necessary, modify the ***Saffir-Simpson hurricane scale's*** treatment of storm surge effects due to hurricanes. The results of the evaluation should be broadly discussed by experts before changes, if needed, are considered for implementation. #8

Establish ***risk-based design methodologies*** for: (1) coastal bridges, (2) communication systems, (3) electricity, water, and gas distribution systems, and (4) roadside signs to resist flooding, storm surge, debris impact, and wind. #10

Adopt and implement existing model code provisions for providing ***alternative/backup electric power supplies*** for all critical facilities and equipment. #12

Conduct detailed performance assessments of ***coastal highway and railroad bridges*** to fully understand and document the factors that contributed to their failure or survival and make recommendations for improvements to future designs. #15

NIST's Next Steps

- Briefings for state and local entities
  - Joint briefings with FEMA in each state for building officials (June 19-21, 2006)
  - Coordinating briefings with national and state associations of building officials
- Briefings for the Office of the Federal Coordinator for Gulf Coast Rebuilding
- Broad dissemination of report and outreach to:
  - Standards and codes organizations
  - Other federal agencies
  - State and local entities
  - Practicing professionals
  - Industry associations
- Collaborative R&D with other agencies (e.g., FEMA, NOAA, USACE, FHWA, USGS) and the private sector on risk-based storm surge maps and evaluation of Saffir-Simpson Scale

Thank you

http://www.bfrl.nist.gov/investigations/investigations.htm